MEMORY

HERING

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LECTURES ON THE SPECIFIC ENERGIES
OF THE NERVOUS SYSTEM

BY

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PUBLISHERS' PREFACE

Dr. Ewald Hering, professor of psychology at the University of Leipsic, is not a voluminous writer, but he has done considerable work in investigating the nature of specific color-sensations and the processes of life. The results of his studies have largely been accepted by his colleagues and his little essay "On Memory" which contains a popular exposition of this fundamental problem has become classical. Concerning its significance for physiology, Prof Michael Foster of the University of Cambridge says in the *Encyclopedia Britannica,* Vol. XIX, page 22:

"If the ingenious speculations of Hering, that specific color-sensations are due to the relation of assimilation (anabolism) to dissimilation (katabolism) of protoplasmic visual substances in the retina or in the brain, should finally pass from the condition of speculation to that of demonstrated truth, we should be brought face to face with the fact that the mere act of building up or the mere act of breaking down affects the condition of protoplasm in other ways than the one which we have hitherto considered, viz., that the building up provides energy to be set free and the breaking down lets the energy forth. In Hering's conception the mere condition of the protoplasm, whether it is largely built up or largely broken down, produces effects which result in a particular state of consciousness. Now, whatever views we may take of consciousness, we must suppose that an affection of consciousness is dependent on a change in some material. But in the case of color-sensations that material cannot be the visual substance itself, but some other substance. That is to say, according to Hering's views, the mere condition of the visual substance as distinct from a change in that condition determines the changes in the other substance which is the basis of consciousness. So that, if Hering's conception be a true one

MEMORY AS A GENERAL FUNCTION OF ORGANIZED MATTER[1]

WHEN a scientist leaves behind him his own special province of inquiry to make an excursion into the realm of philosophy, he may cherish the hope of solving the great problem which underlies the minor questions to which he has devoted his life, but he must be prepared for being secretly discredited with those of his colleagues who still remain quietly at work with the subjects of their specialty, and at the same time must expect the mistrust of the rightful representatives of the empire of speculation. He runs the risk of losing his reputation with the former and of gaining nothing with the latter.

The subject for which I ask your attention on this occasion is a most alluring one; but in accordance with what I have just said, it is not my intention to abandon the domain of natural science to which my studies have been devoted, but only to attempt to reach a higher ground from which we may enjoy a freer and more general survey.

It will seem in the course of this paper as though

[1]An address delivered before the Imperial Academy of Sciences, at Vienna, May 30, 1870.

I am not always faithful to this purpose; for I shall often have occasion to tarry in the province of psychology. Consequently, for my own justification, allow me to point out the extent to which psychological inquiries form, not only an allowable, but also an indispensable accompaniment of physiological research.

The animal human organism with its material mechanism is the subject of physiology. But consciousness is a simultaneous datum. Besides the moving of the atoms of the brain according to certain laws, the inner life of our soul is woven of sensations and conceptions, of feeling and will.

Everyone experiences this in himself; and it is a fact also which beams forth from the faces of his fellow-beings. It breathes in the life of all higher organized animals, and even the simplest creatures bear some vestiges of it. Who can fix the limit of empsychosis in the empire of organic nature?

In the face of such a dual aspect of organic life what can physiology best do? Shall science be blindfolded on the one side, in order the better to comprehend the other?

As long as a physiologist is a mere physicist—and I use the word physicist now in its most comprehensive sense—his method of inquiring into organic nature is altogether one-sided. But it is justly so. As a crystal is to the mineralogist, so to the physiologist of this class is a man or an animal—a mere lump of matter. An animal feels, of course, pleasure and pain, and with the material phenomena of the human body mental emotions are connected; but that is no reason why a physicist should take a different view of the corporeal existence of man, who to him remains a compound of

matter subject to the same irrefragable laws as stones and plants; like a machine, his motions are casually connected with each other and dependent upon their surroundings.

Neither sensation nor conception nor conscious will can form a link in the chain of the material processes of which the physical life of organisms consists. When I answer a question, the initial material process is conducted from the organ of hearing by sensory nerve-fibers to the brain, and must pass through it as a material process in order to reach the motor nerves of the organ of speech. It cannot, after having arrived at a certain spot in the brain, enter into something immaterial, in order to be re-transformed, in some other place of the brain, into another material process. A caravan in the desert might just as well enter the oasis of a mirage, to return thence after a refreshing rest into the actual desert.

Such is the physiologist, so far as he is a physicist. He stands behind the stage and carefully observes the working of the machinery and the movements of the actors, but he misses the meaning of the action which a spectator readily understands. Now, should a physiologist never be allowed to change his point of view?

True, his object is not to understand a world of concepts, but a world of realities. Nevertheless, if now and then he changes his point of observation and looks at things from the other side, or at least accepts from trustworthy observers the results of their experience, he will derive much benefit from such an attitude and will better comprehend both the apparatus he is studying and its methods of working.

For this very reason psychology is an indispen-

sable auxiliary of physiology. If the latter science has hitherto not made much use of the former, it has not been wholly the fault of physiology. Psychology has only lately worked her fields with the plough of induction, and it is only in such a soil that the fruits can be raised for which the physiologist has most need.

The neurologist is thus placed between the physicist and the psychologist. The physicist regards the causal continuity of material processes as the basis of his inquiry; the thoughtful psychologist seeks for the laws of conscious life, and in so doing works according to the rules of inductive methods, assuming the validity of an inalterable order. Now, if the physiologist learns from simple self-observation that conscious life is dependent upon his bodily functions, and *vice versa* that his body to some extent is subject to his will, he has only to assume that *this interdependence of mind and body is arranged according to certain laws,* and the link is found which connects the science of matter with the science of consciousness.

Thus considered, phenomena of consciousness appear to be functions of material changes of organized substance, and *vice versa.* As I wish to avoid all misconceptions, let me mention (although it is included in the term function) that the converse of this assertion means that material processes of the cerebral substance also appear to be functions of the phenomena of consciousness. For if two variables are dependent upon each other according to certain laws, a change of the one demanding a change of the other and *vice versa,* the one is called a function of the other.

This does not mean that the two variables, matter and consciousness, are connected with each other as

cause and effect; for we do not know anything about that. Materialism explains consciousness as the outcome of matter, idealism takes the opposite view, and a third position might postulate the identity of spirit and matter. The physiologist, as such, should not meddle with such questions.

Aided by this hypothesis of a functional connection between spiritual and material facts, modern physiology is enabled to bring the phenomena of consciousness within the domain of its inquiry, without leaving the *terra firma* of scientific method. The physiologist, as a physicist, observes how a beam of light, a wave of sound, or a vibration of heat affects the organs of sensation; how they enter the nerves, are transformed into an irritation of the nerve-fibers and conducted to the brain-cells. Here he loses all trace of them. On the other hand, he observes a spoken word coming from the mouth of a speaking person; he sees the person move his limbs, and finds these movements are caused by muscular contractions produced through motor nerves irritated by the nerve-cells of the central organs. Here again he is at his wit's end. The bridge which should lead him from the irritated sensory nerve to the irritated motor nerve, is indicated in the labyrinthian connections of the nerve-cells, but he lacks a clue to the infinitely involved processes which are interposed in this place.

It is here the physiologist successfully changes his point of view. Here matter no longer reveals the secret to his inquiring glance; but he finds it in the mirror of consciousness, not directly, but indirectly and figuratively—yet in lawful connection with what he inquires into. Here, in observing how one idea re-

places another, how conception rises from sensations, how *Will* starts from conceptions and how emotions and thoughts interweave, he will suppose that there is a corresponding series of interconnected material processes accompanying the whole action of conscious life according to the law of the functional interdependence of matter and consciousness.

After this introduction I may venture to combine under one point of view a long series of phenomena which are apparently widely separated and belong partly to the conscious, partly to the unconscious life, of organic nature. These we shall consider, comprehensively, as the results (*Aeusserungen*) of one and the same faculty of organized matter, viz., memory, or the faculty of reproduction.

Memory, as generally understood, is merely the faculty of voluntarily reproducing ideas or a series of ideas. But if faces and events of past days appear, uncalled for, and take possession of our consciousness, should we not also call this with the same right, remembering? We are justly entitled to include in the concept of memory all involuntary reproductions of sensations, conceptions, emotions, and aspirations. In doing so, memory becomes an original faculty, being at once the source and unification of all conscious life.

It is well known that sensuous perceptions, if constantly repeated for a time, are impressed into what we call the memory of the senses in such a way that often after hours, and even after we have been busy with a hundred other things, they suddenly return into consciousness in the full sensuous vivacity of their original perception. We thus experience how whole groups of sensations, properly regulated in their spatial

and temporal connections, are so vividly reproduced as to be like reality itself. This clearly shows that after the extinction of conscious sensations, some material vestiges still remain in our nervous system, implying a change of its molecular and atomic structure, by which the nervous substance is enabled to reproduce such physical processes as are connected with the corresponding physical processes of sensations and perceptions.

Every one can observe in his daily and hourly experience such phenomena of sense-memory, although in fainter forms. Consciousness produces legends of more or less faded memory-pictures of former sensuous perceptions. They partly are called in voluntarily, and partly crowd in spontaneously. Faces of absent persons come and go as pale and volatile shadows, and sounds of melodies which have long died away haunt us, if not audibly, yet perceptibly.

Of many things and events, especially if they have been perceived only once or very superficially, merely single, unusually striking qualities are reproducible; of other things only those qualities are reproducible which have been remarked on former occasions, our brain being in this way prepared for their reception. Such are responded to more strongly and enter consciousness more easily and energetically. Thus their ability of being reproduced increases. In this way, what is common to many things and hence has been most frequently perceived, will by and by be so reproducible as to be easily called forth by a slight internal impulse, without any exterior and real stimulus. Such a sensation, which is, as it were, produced internally—for instance, the idea of white—is not of the same vivacity

as the sensation of white color externally produced by white light. But it is, after all, essentially the same, being a weak repetition of the same material brain-process and of the same conscious sensation. Thus the idea of white is an almost imperceptibly weak perception.

In this way the qualities which are common to many things are, as it were, separated from them in entering our memory. They attain an independent existence in consciousness as concepts or ideas, and the whole rich world of our concepts and ideals is constructed of these materials of memory.

It is easily seen that memory is not so much a faculty of conscious as of unconscious life. What was conscious to me yesterday and again becomes conscious to me to-day, where has it been in the interim? It did not exist as a fact of consciousness, and yet it returned. Our concepts appear on the stage of consciousness only transiently; they quickly disappear behind the scenes, to make room for others. Only on the stage are they conceptions, as an actor is king only on the stage. As what do they remain behind the scenes? For we know that they exist somehow; a cue only is needed to make them reappear. They do not continue as conceptions, but as certain dispositions of the nervous substance (*Stimmung der Nervensubstanz*) by virtue of which the same sound that was produced yesterday can again be evoked to-day.

Innumerable reproductions of organic processes in our cerebral substance constantly combine with each other, according to certain laws, each in its turn stimulating another; but the phenomenon of consciousness is not necessarily joined with each link of such a series

of processes. Accordingly, chains of conceptions sometimes seem to lack proper connections when conveyed to the cerebral substance through processes unaccompained by consciousness. Therefore, also, a long series of ideas may follow the correct logical order and have a proper organic structure, although the different premises that are indispensable to such combination do not become conscious at all. Some ideas emerge from unconscious life into consciousness, without being connected with any conscious conception whatever; others sink into unconsciousness without ever having been connected with conscious ideas.

Between what I am to-day and what I was yesterday, a gap of unconsciousness lies, the nocturnal sleep; and it is only memory which spans a bridge between my *to-day* and my *yesterday*. Who can hope to unravel the manifold and intricately intertwined tissues of the inner life by simply following the threads of consciousness? You may as well gather your information about the rich organic life of the oceanic world from those few forms which now and then emerge from the surface of the sea merely to disappear again into the depths of the ocean.

Thus the cause which produces the unity of all single phenomena of consciousness must be looked for in unconscious life. As we know nothing of this except what we learn from our investigations of matter, and since in a purely empirical consideration, matter and the unconscious must be regarded as identical, the physiologist may justly define memory in a wider sense to be a faculty of the brain, the results of which to a great extent belong to both consciousness and unconsciousness.

Every perception of an object in space is a highly complicated process. For instance, a white ball suddenly looms up before my eyes. It is necessary, not only to convey to consciousness the perception of white but the circular periphery of the visible ball as well; also its globular form, as it is recognized from the distributions of light and shade; then the exact distance from my eyes must be considered, and from this we form an estimate concerning its size. What an apparatus of sensations, perceptions, and conclusions is apparently necessary for accomplishing all this! And yet the actual perception of the sphere is performed in a few seconds, without my becoming conscious of the single processes which construct the whole; the result enters my consciousness complete.

The nervous substance faithfully preserves the records of processes often performed. All functions necessary for correct perception, which at first operated slowly and with difficulty with the constant help of consciousness, are afterwards reproduced summarily and without an intensity sufficient to push each single link of the chain beyond the threshold of consciousness. Such chains of unconscious nerve processes, which at last end in a link accompanied with consciousness, have been called unconscious chains of perceptions, or unconscious conclusions; a name which is justifiable from the standpoint of psychology. For psychology might frequently lose sight of the soul, if unconscious states were not taken into consideration. To a physical consideration, however, unconscious and material mean the same, and a *physiology of the unconscious* is no *philosophy of the unconscious.*[2]

[2]Refers to Von Hartmann's "*Philosophy of the Unconscious.*"—*Tr.*

Almost all movements which man performs are the result of long and difficult practice. The harmonious co-operation of the different muscles, the exactly gauged amount of work which each one must contribute to the common labor, must be learned for most movements with great trouble. How slowly a beginner at the piano finds the single notes, the eye directing his fingers to the different keys, and then how marvellous is the play of the virtuoso! With the swiftness of thought each note finds an easy passage through the eye to the finger, to be performed correspondingly. One quick glance at the music suffices to transform into sound a whole series of chords; and a melody which has been sufficiently practised may be played while the player's attention is directed to other subjects.

In such a case the *will* no longer directs each single finger to produce the desired movements, and so close attention is not needed to watch the whole execution carefully. The will is only commander-in-chief. The will issues an order, and all the muscles act accordingly. They continue to work as long as they move in their customary tracks, till a slight hint of the will prescribes some other direction.

This would be impossible, if those parts of the central nervous system which bring about the movement were not capable of reproducing entire series of states of irritation. When they have been previously practised under a constant accompaniment of conscious ness, they can be called forth, as it were, independently on the slightest impulse of consciousness, being executed more quickly and more perfectly, the oftener the reproductions have been repeated. All this is pos-

sible only if they remember what they *did* before. Our perceptive faculty would forever remain in its lowest stage if we should consciously construct every single perception from the given single materials of sensation. Our voluntary motions would never surpass the awkwardness of a child, if in every case we should re-incite with conscious will the different single impulses and reproduce over again all our single conceptions; or, to state it briefly, if the nervous motor system were not endowed with memory, i. e., an unconscious memory. What is called "force of habit," is the strength of this memory.

It is to memory that we owe all we *are* and *have*. Ideas and concepts are products of it; each perception, each thought, each motion is carried by it. Memory unites all the innumerable single phenomena of consciousness into one entirety; and as our body would be dispersed into myriads of atoms if it were not held together by the attraction of matter, so, but for the binding power of memory, consciousness would be dissolved into as many fragments as there are moments.

We have seen that only a part of the reproductions of organic processes, as effected by the memory of nervous substance, enters our consciousness; no less important parts remain unconscious. And the same may be proved by numerous facts relating to parts of the nervous system which are exclusively subservient to the unconscious processes of life. For the memory or reproductive faculty of the so-called sympathetic nervous system is by no means weaker than that of the brain and the spinal cord. Medical art, to a great extent, makes good use of this.

In concluding this part of my investigation, let me leave the subject of nervous substance for a moment in order to take a cursory view of other organic matter, where we meet with the same reproductive faculty, but in a simpler form.

Daily experience teaches us that muscles grow stronger the oftener they are used. Muscle-fiber, which in the beginning but feebly responded to the irritation of a motor nerve, works with more energy the oftener it is irritated, after proper intervals of rest. After each single action it becomes more capable of action; it grows fitter for the repetition of the same work and better adapted to the reproduction of the same organic process. *Pari passu,* its size increases, because it assimilates more than in a state of constant rest.

This is the very same faculty of reproduction whose action in nervous substance is so complicated; here it is observable in its simplest form, and easier understood as a physical process. And what is more accurately known of muscle-substance, is more or less clearly demonstrable of the substances of all other organs. Everywhere we find an increased activity with adequate pauses of rest accompanied by an increased strength of action; and organs which are used oftener in the animal economy also grow in size by increased assimilation. But this increase of mass not only means an augmentation and growth of the single cells or fibers of which the organ is composed, but also an augmentation of their number. A cell grown to a certain size divides into filial cells, which inherit, in a greater or less degree, the qualities of the parental cell, and accordingly represents repetitions of it. This growth and augmentation of cells is one of the differ-

ent functions which are characteristic of organized matter. These functions are not only inferior phenomena of the cell-substance, not only certain changes or motions of its molecular structure, but they also become externally visible as a modification of form, an increase of size or a division of the cell. Thus the reproductive function of a cell is manifested also as a reproduction of the cell itself. This is most obvious in plants; the chief function of their cells is the work of growth, while in animal organisms other functions are predominant.

Now, let me finally consider the phenomena in which the power of memory in organized matter is most striking.

On the basis of numerous facts, we may justly assume that even such qualities of an organism can be transferred to its posterity as have not been inherited but have been acquired under peculiar circumstances of life. Thus, every organic being endows its germs with some small inheritance which has been acquired during the individual life of the parental organism and is added to the total legacy of the race.

Considering that properties are inherited which have been developed in different organs of the parental being, it has appeared highly enigmatic to investigators how these same organs could have influenced a germ developed in a distant place. So it has happened that as a solution of this problem mystic views have often been propounded.

The subject may be best comprehended from a physiological standpoint, in this way.

The nervous system, in spite of its being a compound of many thousands of cells and fibers, never-

theless forms one coherent entirety. It is in communication with all organs; according to recent histological researches, it is believed that it is connected with *every cell* of the more important organs, either directly or at least indirectly through a living, irritable, and therefore conducting cell-substance. Through this connection, all organs are more or less interdependent, so that the destinies of the one are re-echoed in the others; and any irritation effected in any one, is transfused, be it ever so feebly, to the remotest parts of the body. In addition to this delicate connection of all parts of the nervous tissue, another, but slower and more sluggish, connection is effected by means of the circulating fluids.

We notice further that the developmental process of the germs destined to attain independent existence, exercises a powerful reaction on both the conscious and unconscious life of the whole organism. And this is a hint that the organ of germination is in a closer and more momentous connection with the other parts, especially with the nervous system, than any other organ. Conversely, the conscious and unconscious destinies of the whole organism, it is probable, find a stronger echo in the germinal vessels than elsewhere.

This, it must be recognized, is the path on which we have to look for the material link between the acquired properties of an organism and those elements of a germ that redevelop the parental qualities.

You may object that an immaterial something cannot be determinative of the future development of germs so like each other; it must rather be the peculiar character of its material composition. But I answer: The curves and planes which a mathematician imag-

ines, or accepts as imaginable, are more numerous and manifold than the shapes of the organic world. But if we imagine infinitely small portions of all these possible curves, they will bear a closer resemblance to each other than germs do. Nevertheless, the whole curve is latent in each portion of it and if a mathematician extends it in its proper directions, it will grow into the peculiar curve which was determined by the form of its small fragmentary part.

Therefore it is erroneous to declare that we cannot imagine such minute differences in germs as must here be assumed by physiology.

An infinitely minute dislodgment of a point or a complex of points in one part of a curve will alter the law in its entire course. In exactly the same way, an evanescent influence of the parental organism upon the molecular structure of its germ is sufficient to predetermine its whole future development.

Accordingly, the reappearance of properties of the parental organism in the full grown filial organism can be nothing else than the reproduction of such processes of organized matter as the germ when still in the germinal vessels had taken part in; the filial organism remembers, so to say, those processes, and as soon as a same or similar irritation is offered, a reaction takes place in it just as formerly in the parental organism, of which it was then a part, and whose destinies influenced it.

If in a parental organism by long habit or constant practice something grows to be second nature, so as to permeate, be it ever so feebly, its germinal cells, and if the germinal cells commence an independent life, they increase and grow till they form a new

being, but their single parts still remain the substance of the parental being, they are bones of its bones, and flesh of its flesh. If, then, the filial organisms reproduce what they experienced as a smaller part of a greater whole, this fact is marvelous indeed, but no more so than when an old man is surprised by reminiscences of his earliest childhood. Whether it still be the very same organized substance which reproduces old experiences, or whether it be its descendant and offspring, a part of itself, which in the meantime expanded and grew, is a difference which, apparently, is one of degree, not of kind. But is it not strange that we are engaged in considering how trifling inheritances of the parental organism can be reproduced in the filial being, as if we had forgotten that the filial organism is nothing but one great reproduction of parental organism, even in its minutest details? This is because we are so accustomed to accept their similarity as granted, that we are surprised to find a child who is in some respect not quite like its mother, and yet the fact that it is like its parent in so many thousand ways is much more wonderful!

If the substance of a germ is able to reproduce what the parental organism has acquired during its individual life, how much more will it be able to reproduce what is innate in the parental organism and has been repeated through innumerable generations in the same organized matter of which the germ of to-day, after all, is, and remains, but a part. Is it then to be wondered at, that the things which organized matter has experienced on numberless occasions are impressed more strongly into the memory of a germ than the incidents of a single life? Every organic being which

lives to-day, is the latest link of an immeasurable series of organic beings, of which one rose into existence from the other, and one inherited part of the acquired properties of the other. The beginnings of this series, it must be assumed, are organisms of extremest simplicity, like those which are known to us as organic germ-cells. In consideration of this, the whole series of such beings appears as the work of the *reproductive faculty* which was inherent in the substance of the first organic form with which the whole development started. When this first germ divided, it bequeathed to its descendants its properties; the immediate descendants added new properties and every new germ reproduced to a great extent the *modi operandi* of its ancestors; part of which grew feebler, because under altered circumstances their reproduction was no longer elicited.

Thus every organized being of our present time is the product of the unconscious memory of organized matter. Constantly increasing and dividing, constantly assimilating new and excreting waste matter, constantly recording new experiences in its memories, to be reproduced again and again, each has taken richer and more perfect shape the longer it has lived.

The whole history of individual development, as observed in higher organized animals, is, from this point of view, a continuous chain of reminiscences of the evolution of all the beings which form the ancestral series of the animal. A complicated perception takes place by means of a volatile, and, as it were, superficial reproduction of cerebral processes which have been long and carefully practised; exactly so a growing germ passes quickly and summarily through

a series of phases which were developed and fixed, step by step, in the memory of organized matter in the series of its ancestral beings, during a life of incalculable duration. This view was repeatedly foreshadowed. It took shape in several theories; but was only rightly understood by a scientist of recent times. For truth hides in different shapes before the eyes of its inquisitors, until it is revealed to the elect.

Not only is there a reproduction of the outward and inner conformation of body, organs, and cells, but of its functions as well. A chick emerging from its shell at once runs off as did its mother, when she as a chick broke her shell. Think how extraordinarily complicated are the motions and sensations of such acts! Only consider the difficulty involved in preserving equilibrium in running, and it will be conceded that the supposition of an innate reproductive faculty alone can serve as an explanation of these intricate actions. The execution of a motion that is exercised during the greater part of an individual life becomes second nature, and the actions of a whole race, repeated over and over again by each member of the race, must also become second nature.

The chick is not only endowed with an inborn dexterity in its motions, but possesses also a strongly developed perceptive faculty. Without hesitation it picks up the grains which are thrown to it. This implies that it sees them, and that it correctly judges their position and their distance; moreover, it has to move its head and other limbs with great precision. All these things could not be learned in the egg shell; they were learned from the many thousands of beings which lived before this chick, and of which it is the

direct offspring.

The memory of organized matter is here most strikingly displayed. The gentle stimulus of the rays which proceed from a grain and fall upon the retina of the chicken gives occasion for the reproduction of a complicated series of sensations, perceptions, and motions, which in this individual have never as yet been combined, and which, nevertheless, were adjusted from the beginning with accuracy and precision, as if the animal itself had practised them thousands of times. Such surprising performances of animals are generally regarded as manifestations of instinct; and some philosophers have indulged in mystic explanations of instincts. If instinct is regarded as the result of the memory or reproductive faculty of organized matter, if we assume that the race is also endowed with memory, instinct is understood at once; and the physiologist is enabled to correlate and connect instinct with the great series of facts we have found to be phenomena of the reproductive faculty. In this way we have not yet gained, but we have certainly approached a physical explanation of the problem.

If, for instance, a caterpillar changes into a chrysalis, or a bird builds a nest, or a bee constructs a cell, such animals, in obeying their instinct, act with consciousness, and are not unconscious machines. They know to some extent how to adapt their actions to change circumstances and are liable to err; they feel pleasure if their work proceeds, and displeasure if they meet obstacles. They learn by working, it must be assumed, and birds, no doubt, build their nests better a second time than the first. But that animals so easily find the most practical means of attaining their ends

the very first time, and that their motions are so excellently and perfectly adapted to their purposes, is due to the inherited disposition of the memory of their nerve substance, which only awaits an occasion to work in full conformity with the situation, and remembers just what is necessary for that occasion.

It is striking how easily dexterity is acquired, if the attention is sufficiently confined to its acquisition. Specialization gives rise to proficiency. He who admires a spider for spinning its web, should bear in mind how limited its other facilities are. Nor should he forget that the spider did not learn its art by itself, but this was acquired slowly by innumerable generations of spiders, and comprises almost all they learned. Man took to bow and arrows if his nets failed to catch him food, but the spider starved.

Thus we see the body and, what is of greater import, the whole nervous system of a newborn animal is predetermined and predisposed for intercourse with the world which it enters; it is prepared to respond to stimuli and influences in the same way as this was done by its ancestors.

We cannot expect that the brain and nervous system of man should form an exception to this rule.

True, man learns with difficulty, while the animal from its very birth is possessed of instinct. However, the human brain at birth is much farther from its highest development than the brain of an animal. Its growth not only takes a longer time, but is much more marked. The human brain, we may say, is much younger when it enters the world than the animal brain. The animal is born precocious, and at once behaves precociously. It is like a phenomenal child

whose brain is overmatured and, as it were, too old, so that it is unable to develop as luxuriantly as another brain, which is less finished, and inured to work, but fresher and more youthful. The scope for individual development in the case of the human brain, and generally of the human body, is much larger, because a relatively great part of its development is relegated to the time subsequent to birth. It grows under the influences of its surroundings, which affect its senses, and acquires under such circumstances, in a more individual way, what an animal has received in the fixed formation of the race.

A far-reaching memory, or reproductive faculty, we must assume, is to be ascribed to the whole body, as well as particularly to the brain of a newborn man. By the help of this memory he is able to acquire much more quickly and easily the attainments which were developed in his ancestors thousands of times and are necessary for his life. What appears as instinct in animals, in man appears, in a freer form, as a predisposition. True, ideas are not inborn in an infant, but the ability of ready and precise crystalization of ideas from a complex mixture of sensations, is due, not to the labor of the child, but to the labor of the brain-substance of innumerable generations of ancestors.

Theories of individual consciousness, according to which it is assumed that each human soul starts life for itself and commences a development of its own, as if the thousands of generations before it had not been in existence, are in striking disagreement with the facts of daily experience.

Those cerebral processes which elevate and dis-

tinguish man, it must be conceded, are not of such antiquity as are those connected with his physical necessities. Hunger and the reproductive instinct have affected even the oldest and simplest forms of organic beings. Accordingly, organic substance has the most powerful memory for these stimuli, as well as for their satisfaction. The impulses and instincts rising from them still exercise elemental power over the man of today. Spiritual life grows slowly, and its most beautiful blossoms belong to the latest epochs of the evolutionary history of organized matter. It is not long that the nervous system has been crowned with the glory of a large and well-developed brain.

Oral and written traditions have been called the memory of mankind, and this conception is true. But there is another memory, which is the reproductive faculty of the cerebral substance. Without it, all written and oral language would be empty and meaningless to later generations; for, if the loftiest ideas were recorded a thousand times in writings or in oral traditions, they would be nothing to brains not predisposed for them. They must not only be received, they must be reproduced. If increasing cerebral potency were not inherited simultaneously with the inward and outward development of the brain, with the wealth of ideas which are inherited from generation to generation, if an increased faculty for the reproduction of thoughts did not devolve upon coming generations simultaneously with their oral and written traditions, scripts and languages would be useless.

The conscious memory of man comes to an end with his death; but the unconscious memory of nature is true and indestructible. Whoever has succeeded in im-

pressing the vestiges of his work upon it, will be remembered forever.

SPECIFIC ENERGIES

THE SPECIFIC ENERGIES OF THE NERVOUS SYSTEM.

JOHANNES MUELLER, the greatest physiologist of our century, in his essays on the senses, established a theory which is well known as "the theory of the specific energies of the sensory nerves." I cannot here recapitulate his doctrine in his own perspicuous language, which would be intelligible only to specialists. But a few sentences will suffice to explain the quintessence of his theory to any one whose occupation prevents him from bestowing more than that kindly interest upon physiology which this most fascinating science awakens in the mind of every educated man.

From the eye and from the ear, from the mucous membranes of the organs of taste and smell, and from the skin of the whole body, which is the organ of touch and temperature, proceed thousands of delicate nerve-fibers. Gradually uniting, they coalesce into steadily enlarging bundles, which either lead directly to the brain, or are indirectly connected with it by the spinal cord. Through these nerve-fibers the sensory organs communicate with the brain, that most wonderful living structure which is both the origin and the product of our consciousness.

When a vibration of ether stimulates the nervous

membrane of our eye (the retina), a process ensues, whose real nature we do not yet understand. We only know that the stimulation is at once transmitted to the fibers of the optic nerve, and in its further progress acts upon those cerebral parts into which the optic nerve enters. As the life of these brain-structures is in close connection with our consciousness, it happens that when a ray of light enters the eye, it causes an irritation of the nervous fibers and of the cerebral cells; and thus we become conscious of the sensations of light and of color.

If now these same rays, which when entering the eye produced the sensation of light, fall upon the skin of the hand, and there stimulate the delicate rootlets of the sensory nerves, this stimulation is transmitted through the nerves and the spinal cord to the brain, and instead of light we are conscious of warmth. How is it that the same external agent in one case produces light, and in the other warmth?

Moreover, the sensation of light can be produced in a perfectly dark room by stimulating the nerves of the eye by an electric current; and if we pass the electric current through the auditory nerve, we hear sounds and noises, though the deepest silence surround us. If we apply the current to the nerves of the skin, we experience the sensation of heat or cold, although not in contact with any cold or warm object, and if by the same current we excite the nerves of the tongue, gustatory sensations are produced. Accordingly, the nervous apparatus of each sensory organ responds to the same stimulus with different sensations. And again we ask: How does precisely the same cause produce such a variety of effects?

Even by the aid of the microscope the anatomist has not been able to discover any essential difference between the various sensory nerves. For instance, that part of the brain which produces the visual sensations does not, in its ultimate structure, vary noticeably from those cerebral regions which produce sensations of sound or temperature. But (and this is the answer to the problem in question) this sameness of form is not accompanied by a sameness of nature. The diverse structures of the nervous system, the nerve-cells and the nerve-fibers, are internally different in spite of all external similarity, and the diversity of the sensations produced is a manifestation of such difference.

It is the nature of the nerve substance in the visual organ to produce sensations of light, and only such. It is the bell which sounds, and not its tongue; and similarly it is not the vibration of ether, but the nerve, that produces light. No matter whether it be a ray of light, whether it be a pressure or a blow upon the eye, an electric current, or any stimulus whatever, that affects the nervous apparatus, it invariably manifests itself as light or color. In the same way we become conscious of the stimulations of the auditory organ in the form of sound or noise, no matter what their cause, which may be aerial vibrations or any morbid irritation of the inner ear, or an organism of the blood.

Johannes Müller called the inherent function of certain nerves to communicate certain sensations, not otherwise producible, to our consciousness, the "specific energy" of those nerves. More than half a century has elapsed since this great physiologist developed his theory in bold and magnificent proportions thus formulating, in scientific terms, an idea, the original germ of

which lies buried in the distant past, as far back as Aristotle. Johannes Müller's doctrines were re-echoed in innumerable writings, but it cannot be said that the seed he sowed fell upon fertile soil, or that it was developed in any essential feature. A few partially successful attempts were made to promote Müller's theory of the sensations of color and of sound, but aside from that his doctrine bore little fruit. On the contrary it was suppressed even by Johannes Müller's own disciples. It again became customary to regard all nerve-fibers as having essentially the same nature, and to suppose that the same kind of stimulation is transmitted in all fibers of the various nerves. The question why the nerves of the various sensory organs produce such different sensations was either entirely abandoned, or it was deemed sufficient to say that the cause should be sought in the brain, although the same reasons which were thought to prove that all nerve-fibers are of the same nature, would hold good also in the case of the brain cells and fibers. Even in some writings of the present day we meet with authors who, confounding philosophy and physiology, declare that the theory of specific energies is one of the great aberrations of physiology.

In consideration of this fact, permit me, as an enthusiastic follower although not a personal disciple of the great scientist, to disclose and reveal the deep significance of the master's doctrine, and to show that it is the application of a principle which has been, or surely will be, accepted in other provinces of biology.

The animal kingdom exhibits an inexhaustible multiplicity of form, and to a layman who is not initiated

into the science of biology it seems almost incredible that living creatures so variously different in their forms and habits, should be so identical in form as germs in the first stage of their development! As a rule, even the most experienced eye, with the assistance of every means of scientific analysis, would not be able to recognize in a germ the animal into which it is going to develop. The fish as well as the bird, and the insect as well as man, so far as we can judge from external appearances, all begin their lives as very simple and microscopically small, spheroidal structures. Nor does this uniformity exist only for the eye; for chemical analysis resolves them all into the same ultimate elements.

We ask, how is it possible that totally different forms can develop from apparently similar germs; and the answer is, that this resemblance of the germs is merely external. By the aid of the most powerful microscopes we can barely discern the roughest outlines of their structures.

In the heavens whole systems of suns appear only as nebulas, which even the most powerful telescopes cannot resolve into single stars. As observation is impossible, we can only surmise their structure. Similarly the ultimate and exquisitely delicate framework in the achitecture of the living substance of germs is withdrawn from the observation of even the minutest research. Could we approach nearer and nearer to one of these nebulas, one star after the other would emerge from the apparently homogeneous mass; we should see planets revolving around their suns, and satellites about the planets. Thus, if with our corporeal or intellectual eye we could penetrate the minutest in-

ternal structure of the substance of germs—if we could comprehend the arrangement and motion of the molecule and atoms—we should discover that the living germ-substance of each animal species has its specific properties, and the substance of each single germ has its individual properties by virtue of which, in a further evolution, a special and peculiar type must mechanically develop.

Whether these internal variations of the germs are chemical or physical is at present immaterial; for the physical properties of a substance are conditioned by their chemical qualities, and when we inquire into the molecular and atomic structure of a substance the dividing line between the domains of chemistry and physics entirely disappears. We cannot in the immediate future, however, hope to find a chemical formula for the individual germ substances. To reveal the delicate secret of living matter by the comparatively crude methods of chemistry would be like trying to explain the mechanism of a watch by melting it in a crucible and examining the molten mass with respect to its ingredients.

As we cannot at present solve the problem of the internal variation of the externally similar germ-substances, we must be satisfied with the statement that the germs of each animal species possess an inherent and innate faculty—i. e., a specific energy, which directs its developments in a manner characteristic of this animal and of no other. Again, each single germ possesses an individual energy which in addition to the normal features of its species secures an individual character to its future development.

Let us now approach our problem from another

side. When the naked eye is not able to discern the more minute organization and delicate structure of an organism, the anatomist employs the microscope, and a new world of discernible facts is revealed to him. The apparently homogeneous form dissolves into innumerable distinct structures; millions of the minutest separately-existing beings, different in shape and internal structure, compose a systematically arranged aggregate, thus forming the diverse organs; and these beings, in spite of the complicated interdependence, lead quite separate lives, for each single being is an animated center of activity. The human body does not receive the impulse of life like a machine from one point, but each single atom of the different organs bears its vitalizing power in itself. The current of life does not emanate from one special part of the body, but all its minutest parts are themselves sources of life. The architecture of the human body, which consists of these elementary organisms, or cells as they are called, has often been explained. The harmonious interaction and the division of labor among these innumerable particles has been compared to the judiciously adapted co-operation of the individual members of a well-regulated community. As in such a community, so also in the human organism, a special kind of work is assigned to each group of individuals, and according to the various functions the elementary organisms are differently formed; but those elements which possess the properly so-called vital power, in every respect exhibit the most striking resemblance, although it may be hidden by and interwoven with various less important solid or fluid ingredients.

In all living cells and fibers of the different organs

we encounter the same colorless viscous, almost fluid, soft unstable substance, in the shape of highly delicate threads, nets, or drops. It is the vital elements of the cell. There the enigma of life lies hidden, for this viscous substance is the moving and creating power in the elementary organism. It produces the contraction of muscular fibers and transmits the irritation in the nerve-fibre; it builds up the solid and strong mass of the supporting bone and the tough fibre of the tendon it shapes the feathers of the bird, the scales of the fish, and the horns of the stag.

Yet it is everywhere apparently the same, and if it is isolated from its proper sphere and surroundings, and considered by itself, the most experienced eye cannot tell which of the different functions was performed by it.

Again we ask, how is it possible that apparently equal causes produce such different effects. Here no one will doubt that in spite of external similarity the living substance in the cells of the individual organs is internally different, and a difference of function necessarily results from this difference of internal structure. It is an innate function. The specific energy of the living substance in the liver produces bile, as the specific energy of the root of a hair builds up the horny mass of hair.

All the innumerable elementary beings or cells of an organism are the offspring of one single germ-cell in which the development commenced. By division, the first cell was split in two. Although both were intimately connected with each other, they were nevertheless, to a certain extent, independent cells. These two cells divided again and formed other cells, and so

on. Thus, by a constantly renewed formation of more living substance the number of the elementary structures increases in almost inexhaustible multiplicity. But in the progress of multiplication the form and arrangement of the cells are also changed. They separate into various homogeneous groups, each of which differs from the others in character in so far as it performs a special function. The living substance is specialized in the process of development according to its function and destination. All the united different specific energies which later on will separately develop to full life in its descendants, lie concealed, although only potentially, in the substance of the germ.

In the light of these considerations the diversity of function in the nervous substance can no longer surprise us. Its external similarity prevents us from considering it as internally different and from claiming for it specific energies according to the doctrine of Johannes Müller.

The specific energies of the living substance in the different organs are characterized by their chemical or physical functions; while in the present state of science the energies of the nervous substance can be recognized only by the different sensations which they produce in our consciousness. Our sensations and all the phenomena of consciousness are the psychological expressions of physiological processes or the stimulations of our nerves,—especially of our brain. *Vice versa,* these stimulations are the material expression of the processes in our soul.

The soul does not act unless the brain is in action at the same time. Whenever the same sensation or the same thought recurs, a certain physical process which

belongs to this special sensation or thought is repeated; for both are inseparably connected. They are conditioned by and productive of each other. Accordingly, from the course of our sensations we can draw inferences concerning the simultaneous and corresponding course of processes in the brain. The resolution of our sensations into their various elements is at the same time an analysis of the involved interactions of the various elementary cerebral functions or stimulations.

For instance, let us suppose that the great variety of the sensations of light and color can be reduced to a few simple or elementary sensations, to those of the principal colors, which by combining in different proportions can produce innumerable different sensations. This fact, if proved, would justify the conclusion that different kinds of elementary stimulations can take place also in the nerve substance of the visual organ. Each of them corresponds to one of the elementary sensations, and the elementary stimulations can be arranged in a manner analogous to that of the elementary sensations. Or similarly, if we succeed in reducing all the many and various gustatory sensations to a few simple sensations, we may again justly infer that a corresponding number of elementary irritations can be produced in the nerve-substance of the tongue.

Consequently the analysis of our sensations leads us to recognize the fact that what Johannes Müller summarily called the specific energy of a sensory nerve may be resolved into a certain number of elementary irritations. But we need not assume that a distinct nerve-element is a medium for each simple irritation. The same nerve-cell can produce the sensation of heat

or of cold according to the direction in which its specific energy is stimulated. The same fiber of the visual organ can be stimulated in different ways and thus convey correspondingly different sensations of color.

Each single kind of stimulus, therefore, does not necessarily correspond to one and the same nerve substance. The specific energy of a certain nerve-element is not merely a simple property, it is not a faculty which causes only one kind of function, it is a multiform potency.

The power of specializing and individualizing its functions is an inborn quality of living substance, and bears its richest and most wonderful fruit in the nervous system. In this respect the nervous system far surpasses all other organs.

One fiber of a muscle performs the same function as all its other fibers, and even the fibers of different muscles possess essentially the very same energy. One liver-cell works as all the other liver-cells do, and it cannot work otherwise. The intensity of a function may be different in the different fibers or cells of such an organ, but the kind of function is common to all.

Not so in the nervous system. The various energies in the various groups of the nervous elements are innate. By an innate faculty the optic nerve of the new-born babe responds to the ray of light which enters the eye with a sensation of light, and the nerve of the skin responds to an increase of temperature with a sensation of warmth.

The specific energy of almost all other organs is definitely fixed at the time of birth and will change in the further development of life in degree only—but never in character.

The muscle-fiber of a babe contracts in the same way, and thus exhibits the same energy, as does the muscle-fiber of an adult person. The liver-cell of an old man produces bile just as does the liver-cell of a child. The muscle and the liver grow with the entire man, but the fibers and cells added can always perform only one and the same function. Some fibers and cells perish in the course of life, but those which take their place merely perform the functions of the replaced fibers and cells.

Thus the innate energy of almost all organs remains unchanged throughout life. The small individual cell-organisms of which the organs consist, come and go, one generation follows another, in some organs more rapidly and in others more slowly. The living substance of each single element is consumed and then replaced by nutrition, but their character and activity always remain the same. In the nervous system all this is very different. Although, as a rule, the innate energies of many regions, especially in the peripheral nervous system, remain unchanged throughout life, there is in the nervous system of a new-born babe some living substance which is ready to be moulded for the performance of this or that function and for the development of this or that *individual* energy.

Above all, the brain of a new-born babe is not a completed structure. It grows and develops; and when the externally visible growth has reached its limits, the internal process of formation continues. Up to the moment of birth the nervous system with the brain is developed according to its own inner law. Until then, neither light nor sound nor any other sensory stimulus has affected the nerves, and the brain has been asleep.

After birth thousands of new stimuli at once intrude from the external world upon the nervous system. The eye is opened to the vibrations of ether and sound-waves obtrude upon the ear; pressure and impact, cold and warmth affect the skin—thus placing the brain which heretofore was left to itself, under the influence and discipline of the external world.

Before birth the chemical processes of the nervous system, its change of matter and its growth, depended upon internal conditions of life. After birth the stimuli of the external world excite the brain and produce a more vigorous exchange of matter for further development and increase of the living substance. The further development, the inner formation and cultivation henceforth depend upon occurrences in the external world which the brain experiences.

All living substance, especially nerve-matter, has the peculiarity that every stimulation produced in a limited region at once spreads to the adjoining parts. It continues spreading as long as it meets with any substance which is capable of being similarly stimulated and which, so to speak, responds to such stimulation.

The specific stimulation awakened in the sensory nerves by external causes, is thus transmitted to the virgin parts of the brain. Here the stimulation terminates in the most youthful and most docile living substance, and here every kind of stimulation finds its echo. For this substance which possesses no innate and definitely specialized energy, has not yet lost its susceptibility for all other stimulations through the frequent repetition of a certain kind of stimulation.

If the virgin substance of the brain is excited and internally agitated by a stimulation which has been

transmitted through the nerve-fibres of the sensory organs, an increased ability to reproduce the same kind of stimulation is acquired by a permanent change of its internal structure. If the sensory nerve again transmits the same stimulation, the cerebral substance responds to it more easily. The oftener it is repeated, the stronger will grow the inclination to reproduce just this kind of stimulation. Through frequent repetition, one particular kind of function becomes, as it were, the second nature of a single cerebral cell, i. e., the cell acquires this special ability or energy. In this way the individual energies of the cerebral cells and fibers are developed by education on the basis of the inherited dispositions. Also the additional energy which the cells acquire during life is transmitted by inheritance to the new-formed cells generated by partition. These new cells can in their turn develop, evolve, or modify the inherited energy.

The anatomical arrangement of the brain is such as to place (single) parts of the so-called gray substance into a particularly intimate relation with special sensory nerves. The stimulation of a sensory nerve-fiber will necessarily seize upon and affect those cerebral cells first which are in closest connection with it. But each cerebral cell is connected with other cerebral cells by a net-work of most delicate nerve-fibers.

The stimulation which enters from the sensory nerve-fibers into the gray substance can advance (through those cerebral elements which are excited first) in all directions farther and farther into the labyrinth of the cerebral cells and fibers, until at last it dies out and ceases sooner or later, or calls forth new stimulations in exchange, which start from the brain and return to

the peripheral nervous system.

Every cerebral element is subject to the educating influence of those sensory nerve-fibers with which it is anatomically connected and whose energies are most closely related to it. But these single cerebral elements can also receive stimulations, although in a weaker degree, from the adjoining fibers of the same sensory nerve and even from those nerve-fibers which enter the gray substance in more remote parts and originate in other sensory organs.

In this way the cerebral substance is constantly permeated with many diverse stimulations crowding upon it from all the sensory regions. The cerebral cell will be particularly educated for the qualities of these stimulations according to its opportunity of easily and repeatedly receiving stimulation from this or that sensory organ and from such or such a sensory nerve-fiber. It will acquire the faculty of reproducing them vigorously, as often as any stimulus is offered, no matter how weak it may be.

Consequently, every single cerebral element attains an individual character in the course of its development and under the influence of sensory experience. And it may be asserted that not even two of the numerous cerebral cells are alike in kind and degree of individual energy. If one cerebral cell is destroyed, there would of course be many others which possess in all essential points the same energy, and can by their functions compensate its loss, but no other cerebral element could do exactly the same work with exactly the same individual ability, with the same ease and exactness; just as no man can in all respects entirely replace another man.

Experience and practice rest upon this specialization and individualization of the functions in the different cerebral elements, and the energies of the nerve substance which are developed in the course of our life are the organic expression of individual memory.

The nervous system, and above all the brain, is the great tool-house of consciousness. Each one of the cerebral elements is a particular tool. Consciousness may be likened to a workman whose tools gradually become so numerous, so various, and so specialized that for every detail of his work he has a tool specially adapted to perform just this kind of work most easily and accurately. If he loses one of his tools, he still possesses a thousand other tools to do the same work although with more difficulty and loss of time. Should he lose these thousands also, he might retain hundreds, with which he can possibly do his work still, but the difficulty increases. He must have lost a very large number of his tools, if certain actions became absolutely impossible.

The knowledge of the tools alone does not suffice to ascertain what work is performed by the tools. The anatomist, therefore, will never understand the labyrinth of cerebral cells and fibers, and the physiologist will never comprehend the thousand-fold intertwined actions of its stimulations, unless they succeed in resolving the phenomena of consciousness into their elements in order to obtain from the kind and strength, from the progression and connection of our perceptions, sensations, and conceptions, a clear idea about the kind and progression of the material processes in the brain. Without this clue the brain will always be a closed book to us.

We can indeed compare the brain to a book. A book is anatomically a number of rectangular white leaves, bound on one side, and marked on their pages with numerous black spots of different form and size. Under a microscope, the leaves will be seen to consist of delicate fibers, and the black spots of minute black granules. A chemical analysis will show that the leaves are cellulose, the spots carbon and resinous oil. If all this has been investigated and ascertained with the utmost accuracy, we do not know in the least why the black spots are arranged just in this and in no other way, why some spots are large and others small, why some occur frequently, others rarely, why the single leaves follow one another in this and in no other order, and altogether what the whole book really means.

Whoever wishes to know what the book signifies, must know the function of the specific energy of each single letter and of the individual energy of each single word—in short, he must know how to read.

Nothing can be fully explained by analogy, and it is perhaps dangerous to attempt to adorn the dry language of science with allegories.

But let the scientist wear his working apparel while ploughing the field of his science; and when, on a festive occasion he offers the fruits of his labor to others, he should be welcome in holiday attire.

NERVE ACTIVITY

ON THE THEORY OF NERVE-ACTIVITY[1]

"A THEORY of nerve-energy would have to show how precisely those properties which are characteristic of the activity of the nerves result with necessity from the multifarious aggregate of the conditions constituting them."

I have taken these words from the *Manual of Physiology* of Carl Ludwig,[2] that memorable man who achieved so much for physiology during his long connection with the university of Leipsic. And now that I am about to develop a special view of my own relating to nerve-activity, it is both appropriate and requisite that I should apply the criterion involved in Carl Ludwig's words to the theory which I am to advance.

If I were asked whether this view could be considered as a contribution to the theory of nerve-activity in the sense indicated by that great master of experimental physiology, I should have to confess that such is not the case; for neither from their constitution nor from their form am I compelled to deduce that property which I am going to attribute to the nerves, however much I may be inclined to assent to Ludwig's dictum

[1]Academic Discourse delivered before the University of Leipsic, May 21, 1898.

[2]Second Edition, page 141.

"that a nerve is indebted for its energy to its constitution and structure," and for a change in its energy to a corresponding change in them.

The source from which I have derived my views relative to the mode of activity of the nerve-fibers, lies quite remote from all the knowledge we now have of their structure and of their chemical and physical properties, and I am therefore perfectly willing that the view which I have put forward as a contribution to the theory of nerve-activity should be regarded only as a conjecture.

In justification of my position, however, I may add that even at best we are in possession only of conjectures concerning the real inner nature of nerve-activity. We know, thanks to Helmholtz, that any sudden alteration in the condition of the nerve-fiber caused by some stimulus, is propagated along the fiber with a measurable speed, and we know further how great this speed approximately is. But the exact nature of that alteration, and the exact character of the process propagated along the fiber, we do not know. Dubois-Reymond's classical investigations have made us acquainted with the electro-motor property of the nerve in its various conditions. But as little as a galvanic current gives us an explanation of the peculiarities of the chemical process to which it owes its origin, so little does the current derived from a nerve give us information concerning the peculiarities of the chemical change in the nervous substance. The assumption that chemical phenomena are the gist of the process which we are wont to designate as the activity of the nerve, is, of course, no more than a mere conjecture. But in making such a conjecture we assert

concerning the nerve nothing more than what might just as well be asserted of all living substances, and nothing is said which would characteristically distinguish the life of the nerve from the life of any other organ.

In fact, life is still as much of an unsolved riddle as it was when the so-called mechanical conception of vital phenomena overthrew the vitalistic, and awakened by its brilliant achievements the most sanguine expectations, foreshadowing results far beyond what has even yet been fulfilled, valuable and fruitful as this has been.

To whatever point the physical or chemical investigation of the animal organism has penetrated, it has always, sooner or later, come upon the mysterious action of the living substance of those elementary organisms of which the animal and the human body are composed. We have now learned modesty, and from having once believed that we had entered the holy of holies, we now acknowledge that we have as yet scarcely passed the portico of the temple. Can it surprise us then that to-day the old fallacious doctrine of vital force which we imagined had been definitely vanquished, should again rear its head under new names? Let us confess that we ourselves are to blame for this because in the first exultation of success we promised more than we were able to fulfill.

Let us cease considering physiology merely as a sort of applied physics and chemistry and thus avoid arousing the justifiable opposition of those who believe it to be an idle task to seek an exhaustive explanation of the living from the dead. Life can be

fully understood only from life, and a physics and a chemistry which have sprung solely from the domain of inanimate nature, and which therefore apply solely to inanimate nature, are adequate only to the explanation of such things as are common to the living and the dead.

This is very much, but it is not all, and I am fain to paraphrase here the words of a brilliant physicist[3] who has used them in an analogous connection, and say: If the assertion that physiology is only applied physics and chemistry be taken to mean that the laws discovered in the domain of physics and chemistry are sufficient without extension and generalization to explain fully the phenomena of life, "we are, in my opinion, confronted with a view which is in all respects comparable to that of Thales, who endeavored to explain everything from the properties of water. Think of the improbability that a wide domain of experience can be absolutely exhausted by a narrower one previously known." If everything that took place in nature could be designated outright as physical or chemical, whether it was subsumable under the present known laws of physics or chemistry or not, then naturally all phenomena of life would in such a case fall within the domain of physics and chemistry. But we cannot hoist our flag over a territory where we have never as yet set foot, much less explored.

At bottom, it was not the mere negation of vital force at this juncture that secured for physiology its brilliant successes, but rather the concomitant introduction into biology of the rigorous methods of phys-

[3]E. Mach, *Die Principien der Wärmelehre*, p. 351.

ical science and of the great mass of apparatus and appliances which had been created by those methods; and only in so far as vitalism persisted in employing unproductive methods for treating biological problems did it do real harm and was its overthrow of real benefit. In fact, every observed attribute of life which was susceptible of immediate physical explanation had already been physically explained in the heyday of vitalism. The laws of the lever were applied to the movement of the human members, and the movement of the blood attributed to the contraction of the muscles of the heart, even at a time when the muscular activity itself was still conceived in characteristically vitalistic fashion. Even to-day we cannot explain this last-named activity, although it is one of the most palpable and most obtrusive of the actions of living things.

The impulse to resort to analogy and to carry over propositions abstracted from one domain into others is so great that there can be no fear that any phenomenon of life will long remain exempt from physical or chemical explanation after physics and chemistry have supplied the requisite means. To-day, the danger of precipitate and therefore of insufficient physico-chemical explanation of vital phenomena is perhaps greater than the danger of that vital force should continue to be employed (to use a celebrated saying) "as the comfortable couch where reason is quieted upon the pillow of obscure qualities."

Even the mechanical theory of life has not been able to prevent the substitution of a new dogmatism for the old vitalistic creed, and in adducing a striking instance of this fact I reach the real subject of

my present discussion.

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I have already stated that the process which is propagated along a nerve-fiber in the shape of a so-called excitation is in its real nature unknown to us. Nevertheless, it is accepted as an established fact by most physiologists to-day that this excitation is always of exactly the same kind, not only in one and the same nerve-fiber but in all nerve-fibers; and that it can consequently undergo alteration only with regard to the strength and time of its propagation, but not as regards its quality; and that, therefore, all functional differentiation of the nerves is exclusively resident in either their central or their peripheral terminal apparatus. So thoroughly convinced are many physiologists of the truth of this view, that they absolutely refuse to consider any theory which assumes a qualitative variability in the excitations which pass through the nerve-fibers. And they do this in the consciousness that they are supported by the authority of a Helmholtz, a Dubois-Reymond, and a Donders.

But let us examine for a moment the meaning of the assertion that the excitations are absolutely alike in all nerve-fibers.

If it were possible to insert a portion of a sensory nerve into the path of a motor nerve, and to connect the former with the latter, fiber for fiber, a cerebral excitation of the motor nerve would pass unaltered through the inserted piece of sensory nerve to the muscle, which it would forthwith set into activity. Or, if we could cut out a piece of the optic

nerve and insert in its place a piece of a motor nerve, and combine every fiber of the former with every fiber of the latter, functional continuity would be restored along with the anatomical continuity, and the perception of light and color would be possible just as before.

Finally, let us imagine the optic nerve and the auditory nerve severed, and each brought into conjunction with the other crosswise. According to Dubois Reymond, we should in such a case hear the lightning with the eye as a noise, and see the thunder with the ear as a succession of light-impressions.

Of such a character are the consequences that flow from the assumption that the functions of the nerve-fibers are all absolutely alike. The impossibility of actually realizing the hypothetical cases which have been adduced affect in no wise the correctness of the conclusions drawn from them.

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What, now, are the considerations that could have led to the enunciation of a definite opinion regarding processes which are still involved in so much mystery for us? Carl Ludwig himself once considered the question of the likeness or unlikeness of the nerve-fibers, and did so with all his wonted caution, but he finally left the question undecided, as did also Johannes Müller in his time. Since then, no new facts have been brought to light which could have tended to confirm the theory of the homogeneity of the nerve-fibers, as Ludwig called it. For the experiments in the grafting of the peripheral terminals of severed nerves, with the central terminal of

a nerve having different functions, even if they had been successful, could not have decided our question. And yet, by the majority of physiologists the theory of homogeneity is regarded to-day as an established truth.

By his *Investigations in Animal Electricity* Dubois Reymond[4] believed he had "awakened into lifelike reality the hundred years' dream of the physicists and physiologists regarding the identity of nervous energy and electricity, even though in a slightly changed form." The facts which he adduced have been confirmed in all their essential points, and although their interpretation has turned out to be different from what he conjectured, yet the opinion which he cherished, according to which the essential nature of nervous activity found its expression in electrical phenomena, is still shared by many physiologists to-day. Now this view was in its time, and is to-day, so far as I can see, the principal foundation of the conviction which so generally obtains in the scientific world regarding the homogeneity of the nerve-fibers and of their excitations.

When we set a nerve in excitation at any point of its course by an artificial stimulus, the propagation of the process of excitation can be followed step by step along the path of the nerve by means of a galvanometer, for the reason that the electric behavior of the nervous substance changes precisely as the condition of the nervous substance itself changes in passing to the excited state. The galvanometer then shows us the current of action, or at the severed terminus of the nerve the so-called

[4]Preface, p. 15.

oscillation of the current of injury. It was rendered highly probable by Dubois Reymond (and later investigations have only confirmed the conjecture) that these electrical phenomena are characteristic of all nerves, and that they accompany not only the excitations which have been produced by artificial stimuli, but also such as are disengaged in the natural way from the central or peripheral terminal apparatus of the nerve-fiber. If now the electric phenomena were the expression of the real inner character of the excitation passing along the nerve, the homogeneity of the latter would follow immediately from the homogeneity of the former; and different nerve-fibers could exhibit different behaviors only with regard to the intensity and time of action of the excitation.

It was afterwards discovered that the electric phenomenon in question admitted of scarcely any other explanation than that of a chemical process propagated along the excited nerve. Yet even this discovery could not shake the theory of homogeneity.

After that theory had once taken root, the identity of the chemical process was deduced immediately from the identity of the electrical behavior, and the idea never suggested itself that we might with just as good reason infer the identity of two chemical processes from the identity of their thermal effects, or the identity of the chemical transformation in two galvanic elements from the identity of their currents.

The electrical phenomena which accompany the excitation of the nerve furnishing no adequate foundation for the theory of homogeneity, the next natural support likely to be resorted to for this theory is

that of the morphological and chemical homogeneity of the nerve-fibers. It is quite true, we are as yet unable to distinguish by the microscope and by chemical reactions every motor fiber from every secretory fiber, and every optic fiber from every auditory fiber. But the cases are numberless in which living elementary structures having different functions exhibit absolutely the same behavior when subjected to known optical or chemical tests.

The germs of quite different species of animals are frequently so much alike as to be confounded with one another; and the germs of different individuals of the same species naturally show a still greater degree of similarity. Yet no biologist has the least hesitation in ascribing to each individual germ some quite specific individuality, some personal idiosyncrasy, so to speak, of inward structure or molecular constitution by virtue of which a perfectly definite path of future development is marked out for it.

It is regarded as almost certain that the different functions of the secretory cells of the various glands are attributable to the physical and chemical differences of their vital substance, and yet in many cases it would be quite impossible by the microscope and micro-chemical methods at our command, to determine the actual function of any single glandular cell.

It was shown by Max Schultze many years ago, and recent inquiries have confirmed his results,[5] that while the pseudopodia of the same rhizopod merged and fused perfectly on contact, the pseudopodia of

[5]Paul Jensen, "Ueber individuelle physiologische Unterschiede zwischen Zellen der gleichen Art." Pflüger's Archiv für die ges. Physiologie. Bd. LXII., p. 175. 1895.

different individuals of the same species would not fuse on being brought together. Now, if the protoplasm of two individuals of the same species were absolutely of the same composition, it would be difficult to see why their pseudopodia should not behave with regard to one another precisely as the pseudopodia of the same individual do.

We are obliged, accordingly, to attribute to the living substance of every single one of these minute and inferior creatures, specific individual properties, by virtue of which their substance is distinguished from the substance of every other individual of the same species; although there cannot be, even in so patent a case as the present, the remotest thought of directly demonstrating these inferred differences by the experimental means of investigation at our command.

But if a distinctive individual stamp must be imputed to every one of the countless members of the same rhizopod species, why shall some such distinctive mark be refused to the elementary organisms of which the nervous system is composed? The fact that the rhizopods lead an independent life, while the nerve-elements are rigorously subordinated parts of a more highly developed organism, is no reason whatever for our not doing so, seeing that each individual nerve-fiber is connected with a vast and most varied host of vital functions, and that consequently it can be highly differentiated according to the principle of the division of labor; whereas no such division of labor can come into consideration in the case of the individuals of a rhizopod species.

In this division of labor of our organism lies, in

fact, part of the answer which I should give to the advocates of the theory of homogeneity, if they were to ask why I am anxious to assume heterogeneity in places where the assumption of homogeneity appears to be adequate to explain the function of nerve-fibers as simple organs of conductivity. The argument that I have adduced, they would contend, proved at most that the sameness of all the fibers cannot now be directly demonstrated, that there are even reasons for suspecting them to be not the same, but that in any event no counterproof to their theory is furnished. Even the wires which conduct electricity, they would say further, may be put to very different uses, and yet the electrical phenomenon in the conducting wires is qualitatively the same.

The fact that the excitation of a glandular nerve produces a secretion, while that of a muscle-nerve produces a movement, is sufficiently explained by a difference in the terminal apparatus upon which those nerves act; and there is just so much ground and no more for supposing a qualitative difference of excitation to result from a difference in the stimuli by which the nerves of the several sense-organs are excited. The further fact, they would continue, that sound is able to excite the auditory nerve and light the optic nerve is due entirely to the different structure of the apparatus at the peripheral end of these nerves,—one apparatus being especially adapted for the reception of sound-waves and the other for the reception of light-waves and for their transformation into nervous excitation. If the sound were to strike directly upon the auditory nerve itself, and not on the peripheral apparatus, if the light were to fall di-

rectly upon the optic nerve itself, these nerves would not be excited,—a proof that the so-called specific excitability of the various sensory nerves is not due to any dissimilarity of the latter, but entirely to the differences of the terminal apparatus which receive the impression.

In answer to this oft-repeated argument, it must be frankly confessed that so far as our present knowledge goes, no conclusion whatever follows from the varying behavior of the sense-organs toward different sensory stimuli in favor of the assumption of a specific heterogeneity of the sensory nerve-fibers; but neither does anything follow in contravention of such an assumption. And it must be further admitted that considering the dissimilarity in results which follow upon the excitation of nerves that act centrifugally according as they set a muscle or a gland in activity, no conclusive argument is forthcoming either in favor or in contravention of the homogeneity of these nerves.

But the situation assumes a different aspect when we consider the manifold results to which the excitation of such sensory nerves leads as have not their terminus in such heterogeneous organs as the muscles or the glands, but all end in the brain. For instance, we are compelled to inquire how it is that the excitation of one nerve brings with it the sensation of light and color, that of another the sensation of sweet and sour, that of a third the sensation of heat and cold, while at the same time all these nerves carry to the brain excitations which are absolutely the same in quality. To this the theory of homogeneity has always answered without the least

ado that it is because the like nerve-fibers of the tongue and of the eye lead to unlike nerve-cells in the brain, some of them to cells whose specific character enables them to take up the excitatory conditions that correspond to the sensations of taste, others to cells which, conformably to their specific function, respond to the excitation of the fiber with precisely that physiological process whose psychical correlate is a sensation of light.

And here finally we are met with the frank concession that interior commotion of the nervous substance which we call excitation or activity is, at least in the various sensory centers of the brain, specifically differentiated, and that here at last the functional homogeneity reaches its termination.

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While this doctrine was taking its development,—a doctrine according to which all the nerve-fibers are exactly the same in kind, but the terminal apparatus which are functionally connected with them are different in kind,—the idea necessarily suggested itself of separating the nerve-fibers as a particular group of elementary structures from the nerve-cells; but, even at the period of the development in question, it would have been quite admissible, in view of the anatomical continuity which had been established in numerous instances between cells and fibers, to have inquired by what right physiologists ascribed to the cells functions which varied in character, whereas they denied to the fibers connecting them all specific dissimilarity whatever, and did so in spite of the fact that chemical and physical research had not been able to dis-

cern any more characteristic differences in the substance of the cells than it had in the axial cylinder of the fibers.

Since that time, a different conception of the elementary structures of the nervous system has found almost universal acceptance. According to this theory, every nerve-fiber is associated in such wise with a nerve-cell as to form with it a single elementary organism only; and the living substance of that organism, which is collected in more abundant quantities about the nucleus of the nerve-cell, is continued into the fibers. Accordingly, the nerve-fibers would be integral constituents of these elementary structures of the nervous system, or "*neurons*," as they are called. On this theory, the idea is quite natural to ascribe to the fibers which continue the cells the same specific differences which physiologists were obliged to assign to the nerve-cells of the various cerebral centers.[6] But as soon as we do this, we no longer have before us cells which, though capable of performing different tasks, are yet connected by filaments having quite the same functions, but we have elementary organisms whose specific or individual dissimilarity extends to their remotest filar prolongations. A nerve-trunk is no longer a mere bundle of conducting wires disengaging different sorts of effects, according to the kind of apparatus with which they are connected at their termini and being at the same time in their own specific function absolutely of the same kind; but it is a bundle of living arms which the elementary organisms of the nervous system send forth for the pur-

[6]I offer no opinion as to the correctness of the histological doctrine of neurons. I lay it at the foundation of the present discussion because my theory needs some definite histological substratum.

pose of entering into functional connection with one another, or of permitting the phenomena of the outside world to act upon them, or of exercising control over other organs like the muscles and the glands. And in each one of these arms a quite special kind of life is active, corresponding precisely to the neuron to which the nerve-fiber belongs. The conducting path which unites a sense-organ with the cerebral cortex, or the latter with a muscle, appears as a chain of living individuals of which every member, although always dependent upon its neighbors, still leads a separate life, the specific character of which is generally different in the different parts of the nervous system. Even in the neurons of the same group it is not absolutely the same, but bears in each of them a more or less individual stamp.

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The theory of the homogeneity of the excitatory process in all the nerve-fibers involves the further assertion that this process remains qualitatively the same in one and the same fiber, and that it is variable only as to intensity and time of propagation.

I once advanced views relating to the processes in the nerve-apparatus of the visual organs which presupposed that in one and the same retinal element different processes could be set up by light-waves of different rates of vibration. The physiologists declared such a view inadmissible inasmuch as more than one process in the same structural element would presuppose more than one conduction-process in the corresponding fiber, a view which physiology was

forthwith compelled to repudiate.[7] And this dogma, according to which every nerve-fiber is held to be capable of only one kind of excitation, had actually been extended also to the nerve-cells. True, as already said, physiologists were even then compelled to ascribe to the nerve-cells of the different sensory centers different functions; but in one and the same cell the excitation was said to be of unalterable quality.

It was no less an authority than Helmholtz who introduced this conception into the physiology of sensation, and to-day his disciples still esteem the doctrine of cerebral cells sensitive only to red, green, or violet, as the rarest fruit of Johannes Müller's doctrine of the specific energies of the sensory nerves. But I am convinced that Johannes Müller would not have accepted such a view, for his conception of biology was thoroughly monistic, and he would not have denied to the cell of the brain what must be conceded to the lowest unicellular organism, namely, a more or less wide qualitative variability of its inner life.

Who can deny that the chemical changes in the substance of an infusorian vary qualitatively according to the changes in its external life-conditions; for example, in food material, or in other stimuli acting upon its body? And even granting that the progressive division of labor which accompanies the increasing structural complexity of the animal organism, in general brings more structural uniformity into the life of the individual cells, still there is no ground for the view that just in the nerve-cell this uniformity can become as complete as the homogeneity theory

[7]Donders, "Ueber Farbensysteme," *Arch. f. Ophthalmol.*, XXVII. 1881.

demands.

Granting, however, the possibility of qualitatively different excitation-conditions in the same cell (and in the fiber springing from it), then there is opened for the theory of nerve-life a series of points of view which are quite excluded by the homogeneity theory.

At the outset it follows that a neuron which is capable of various kinds of activities, will possess a correspondingly complex excitability, that is to say, it will vary in its reactions according to the nature of the stimuli, it will respond by one or another of its habitual special activities; in brief, the activity of the neuron and of its fiber may vary, not merely, as has been supposed, in intensity but also in quality, according to the nature of the stimulus, whether this be exercised by an external sense-organ, or by an adjacent neuron. A further consequence of our view would be that the effects in those non-nervous elementary organs with which centrifugal fibers stand in functional connection, might also vary with the kind of excitation conducted in the fiber.

For the motor fibers, of course, there is, owing to the uniform action of the muscle-fiber, no apparent reason for such a view. It is different, however, with the nerve-fibers which govern the activity of a gland. The view now generally accepted is that, in conformity with their unalterable homogeneity of excitation, these secretory fibres can influence the activity of their dependent gland-cells only quantitatively. But how would it be if, according to the nature of the excitation given by the nerve-fiber, the chemical processes in the secretory cells were different, and con-

sequently the nervous system could affect, within certain definite limits, the *quality* of the secretion furnished by one and the same cell?

And would not similar views hold in regard to the so-called trophic activities of centrifugal nerves? Inasmuch as these activities do not, as in the case of the motor or secretory nerves, immediately reveal themselves by easily demonstrable movements, they have hitherto remained rather within the domain of conjecture than in that of safely ascertained facts. If, however, the nervous system exerted an immediate influence, not merely on the motor and secretory, but also on the other elementary organs of the body (e. g., on certain epithelia, on the developing cells of the ovary, etc.), then here, too, the answer to the question whether such an influence were variable only according to quantity or also according to quality, would be of far-reaching influence.

But let us turn back to the activities which the excitation of a neuron exercises on those other neurons with which it is connected.

If, as histology teaches us, a sensory fiber entering the spinal cord divides into an ascending branch and a descending branch, and from these latter there branch off the so-called collaterals which finally stand in relation with other neurons (it matters not whether through direct contact or through connection); if finally every one of these neurons by its branching stands in functional relation with still others, and so on; then, from a purely anatomical standpoint, there exists for an incoming excitation an incalculable multiplicity of paths through the central nervous system. If now an excitation which has seized a neuron,

should pass on indifferently to all the other neurons with which the first is functionally connected, there would result an exceedingly widespread diffusion of the excitation entering through a sensory fiber or coming from a neuron to the cerebral cortex, a diffusion such as is not known to exist, or, at the most, is only approximated to in motor effects under pathological conditions.

It must consequently be assumed that the excitation of a fiber does not take indifferently all the anatomically given ways, but selects predominantly certain determined paths, diffusing itself in the others only in a more or less enfeebled manner or only exceptionally; and the question hence arises: What is the determining factor for this choice, and for the varied ratio of the strengths with which the excitation propagates itself along the many possible paths?

The homogeneity theory finds the answer in the different degree of excitability and conductivity of the individual paths, and in the different amounts of resistance offered to passage from one neuron to another. As for the further diffusion this is made to depend entirely on the strength of the incoming stimulus.

Numerous facts from the sensory and motor territories of nerve-life teach us that the innervation issuing from a neuron can diffuse itself in the nervous system very differently according as certain other excitations take place at the same time. For example, though the stimulus be the same, a reflex movement is sometimes reinforced and sometimes inhibited by excitations issuing simultaneously from another place on the periphery of the body or from the brain.

Accordingly, the homogeneity theory accepts the view that resistance to conduction in a neuron can sometimes be increased and sometimes lessened by excitations which reach the same neuron from another direction, in other words that sometimes a so-called path-breaking, sometimes an arrestation takes place; but it does not further explain how excitations which are said to be always of the same kind and to differ only quantitatively, can at one time operate on the neuron so as to promote, and at another time so as to arrest, its function.

Everything is seen in a different light, however, as soon as a qualitative variability of the conducted excitation, and also a qualitatively different excitability of the conducting paths, are admitted. If the individual nerve-fiber is suited for the taking up and transmission of definite qualities of excitation, either preferentially or exclusively, *then the path which is taken by an excitation is coincidently determined by the quality of that excitation.*

As a report is principally taken up and circulated by those who take a special interest in it, that is to say, the paths of its spreading depend on the nature of its contents, so to a definite afferent excitation those neurons will react preponderatingly whose peculiar nature precisely corresponds to that excitation.

The mutual relations of neurons will then depend not merely upon their anatomical arrangement, but also on their degree of internal structural affinity. And as one and the same fiber need not be adapted merely to *one* kind of excitation, but may be adapted to a certain number (though within a narrow range),

so not only will the same path be able to conduct various kindred qualities, but the excitation issuing from the same neuron will be able, according to its particular quality, to penetrate various parts of the nervous system.

If, further, excitations should be simultaneously brought to the same neuron by two of its neighbors, then according to the homogeneity theory these excitations could on meeting only strengthen or weaken each other. According to our view, however, the two excitations could be of different kinds, and from their meeting in the same substance might originate a new quality, which would indeed be closely related to the two single excitations, but not like either.

And generally the whole life and being of the nervous system, its ontogenesis and phylogenesis, appear in a totally different light as soon as we give up the dogma of the absolutely homogeneous function of all nerve-fibers, and ascribe to the individual fiber-groups characters. For that dogma excludes from the neuron every capability for development and improvement, in so far as such capability is not already inborn and in so far as it is not a mere augmentation of its excitational or vital process, which latter is from the beginning to the end of its life supposed to be peculiar and unalterable.

Rightly have the opponents of the doctrine of the specific energies of the sensory nerves pronounced against the view of a life-long unalterable constancy of function of the nerves, but they went too far, as I conceive, when they contested the congenitally different and special nature of the individual sensory

nerves, accepted the indifference of function of all sensory fibers of the new-born, and regarded all functional differences of nerve-fibers, which are the phylogenetic acquisition of innumerable generations, merely as the result of an adaptation to heterogeneous, individual sensory stimuli during the post-embryonic period.

Of course after birth the influences of the external world belong to the conditions of the further normal development of the whole body, and the sensory stimuli especially are indispensable conditions of development of the nervous apparatus of our sense-organs. But light, for example, does not find in the eye of the new-born babe a nerve-substance from which, so to speak, anything whatever can be made; in other words, a substance which, if it could be transposed from the eye into the ear or into the tongue could be educated by the sound-waves to a medium of auditory sensations, or by gustatory stimuli to be a medium of taste-sensation.

As the germ sprouting from the earth needs light to become a green plant, so in the new-born babe the neuron in the eye needs light, and the neuron in the ear the sound stimulus, to complete its course of development; but just as light never makes the fungus green, so it could never make the neurons of the ear to see if they should be transplanted into the eye. As I take it, the neurons of our eye are not merely *educated,* but are *born* for seeing, and likewise those of our ear for hearing.

This, however, does not exclude the fact that, within their own narrow congenital limits of existence and action, they are capable of further indi-

vidual development. And the same holds good (sometimes more, sometimes less) of all parts of our nervous system. It is true, the farther back in the immeasurably long developmental series of the animal organism a given part of it can be traced, the more fast and sharp is the congenital stamp of its function, and the less capable does it appear of transformation and development in the course of its further life. But the cerebral cortex is reckoned among the phylogenetically youngest parts of our nervous system, and its neurons belong, as it seems, to those elementary bodily organs which in post-natal life are afforded the relatively widest sphere of individual action under the influence of impinging stimuli. Now, how is such a development conceivable if the internal activity of a nerve-fiber or a nerve-cell, in brief a neuron, is to be always of one and the same kind?

What is it then that a neuron of our cortex under normal circumstances experiences? In other words, of what do the stimuli which encounter it and determine its internal activities, consist? Under constant conditions of nutrition, these are mainly the excitations conducted to it from those other neurons which stand in relation to it by means of the nerve-fibers. If, however, these nerve-fibers always conduct to it only the same kind of excitation, have, so to speak, only one note to their lyre, and therefore the stimuli which the neurons experience throughout life are the same and are variable only in quantity and time, then the reaction of the neuron will also always be one of the same kind, and the afferent stimulus can only liberate in the nerve-cell forever *the same* activity. And if, as the homogeneity theory concedes, the lat-

ter could be different in the different nerve-cells, still in one and the same cell, and in so far as it depends upon the afferent excitations, it would remain the same its whole life long.

It will be altogether different, however, if these excitations vary qualitatively, according to the nature of the neighboring neurons from which they come, or if the afferent excitation from one and the same neuron may vary within certain qualitative limits. Then a more or less rich multiplicity of excitations will take the place of the just-mentioned monotony that the neuron experiences from its neighbors, and, as this neuron is in its turn capable of heterogeneous activities, there is also opened to it the possibility of reacting to different impulses in different ways.

The nature of this reaction will, of course, also be determined by the inborn individuality of the neuron; but of the entire stock of innate qualities which it brings with it from birth those will be most fully developed in the course of its life to whose development the neuron is most frequently or most strongly excited by its neighbors. Or, briefly stated, the neuron will possess the capability of qualitative and not merely of quantitative development, which last would, according to the homogeneity theory, alone be possible to it.

According to its place in the nervous system, its more or less manifold relations to other neurons and its inborn structure, this subsequent development will be more or less many-sided, and the doctrine of the homogeneity-theory that the sameness of excitation which the neurons experience conditions a corresponding uniformity in their further development, may per-

haps approximately hold for entire large groups of neurons. On the other hand, however, all experience or training both sensory and motor,—in brief, everything that can be called conscious or unconscious memory in the widest sense of the word,—is to my mind not conceivable unless the living substance of the nerve-cells and fibers is capable of a qualitatively variable development.

I have sought in vain in the writings of those supporters of the homogeneity theory who have occupied themselves with considerations concerning the physiological foundations of nutrition and exercise, for a satisfactory conception of the subject. For an explanation of the development of the central nervous system corresponding to the physical development, we are with reason directed to the possibility of the origin of new connections between the neurons, to alterations of excitability and conductivity in the paths already provided, to the opening and the increasing erosion of certain old paths by use, etc. On all these, old or new, pervious or impervious paths, however, that which is conducted through the nerve-fibers still remains (according to the homogeneity-theory) always the same, and everywhere it is a matter only of moreness or lessness and of variable velocity. The whole nervous system, according to this theory, appears like a land whose numerous communities are connected by a richly developed network of road, on which latter, however, always and everywhere, only one and the same kind of wares is transported.

Writers love to compare the nerve-fibers with telegraph or telephone wires, and they will consequently,

perhaps, point to the endless multiplicity of things which can be transmitted through wires of exactly the same kind. The comparison is seductive, for if spun out farther it seems suited to solve all difficulties at a single stroke.

In place of the undoubtedly "obscure" specific or individual "qualities" of the nervous processes of which I have spoken, appears a multiplicity of oscillations of different temporal and spatial form, of which the nerve-substance is the mere *vehicle*. But all come finally to exactly the same result with this comparison as I do. For it must be admitted that neither in all nerve-fibers is the same oscillation-form always transmitted, nor is every individual nerve-fiber susceptible of all the oscillation-forms which are possible to the nerve-substance generally, but only of those to which it can respond.

What we have named the specific energy of the fibers or cells reappears here as special resonance-capacities corresponding to definite oscillation-forms. What we formerly called an inborn, acquired or individual characteristic, becomes here the pitch; and, as with us, the specific excitabilities, so here the resonance and previous attunement of the neurons determine the paths in the nervous system which a given oscillation-form shall enter upon.

We accordingly acquire only another mode of expression for one and the same thing; and, as I conceive, one not corresponding so well to the facts, inasmuch as it takes no account of that which in an entirely unique way characterizes all life, namely, metabolism, that chemical change in the living sub-

stance whose qualitative differences it is at present (and may be forever) impossible to express by purely quantitative spatial and temporal terms.

From all that has been said it immediately follows that I not only agree with the teaching of Johannes Müller, but would like to see the scope of his conception much broadened. The specific energies are in my opinion a phylogenetically acquired heirloom, not merely of the sensory nerves, but more or less of *all* neurons, of their fibers as well as of their cells. But I consider that the inheritance allotted to the individual neuron is by no means so sparing and uniform as was assumed in the case of the cells of the sensory centers, and further that it was not bequeathed with a codicil that the heir should not add any newly acquired riches to his inheritance.

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